CO_2 COOLING IN TERRESTRIAL PLANET THERMOSPHERES

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The comparative approach to planetary problems is becoming increasingly fruitful as new information from various planetary atmospheres is assimilated. As an example, it is clear that the important problem of CO_2 cooling in the Earth's lower thermosphere is closely tied to the thermospheric heat budgets of Venus and Mars.

The thermospheres of Earth, Venus, and Mars are cooled by a combination of molecular/eddy conduction and infrared (IR) cooling processes. Molecular conduction cools the upper thermosphere by transferring the EUV or auroral heat down-gradient toward the mesopause, where it is effectively radiated to space by an IR active cooling agent. The height and temperature of the mesopause are controlled by the effectiveness of the IR cooling processes. For all three planets, this IR cooling results primarily from CO_2 emission at 15-μm. Atomic oxygen collisions are known to be especially effective in exciting CO_2 vibrational states, resulting in enhanced CO_2 15-μm emissions and cooling at thermospheric heights where non-Local Thermodynamic Equilibrium (NLTE) prevails. The effectiveness of this enhancement process depends upon the relative O densities at a given pressure level plus the collisional energy transfer rate coefficient (CO_2-O) specified. The importance of this mechanism for enhancing CO_2 cooling on Earth and Venus has been debated since 1970. For Venus, a longstanding dayside heat budget problem can only be resolved by understanding the relative role of CO_2 cooling [1,2,3]; the Venus atomic oxygen density is well measured over the solar cycle. For the Earth, the lower thermosphere heat budget is difficult to understand without a thorough characterization of the variability of atomic oxygen and CO_2 cooling in that region.

Progress has been made recently that improves our understanding of CO_2 cooling processes in the Venus, Earth, and Mars lower thermospheres. First, the corresponding CO_2-O relaxation rate has been measured in the laboratory at room temperature for the first time ($k = 1\text{-}2 \times 10^{-12}$ cm^3/sec). Also, derived values of this relaxation rate are becoming better constrained ($1\text{-}6 \times 10^{-12}$) and are based primarily upon analyses of Earth CO_2 radiance and absorption measurements (see Table 1 and references therein). We see that these recently measured and derived values are not entirely consistent. Furthermore, the temperature dependence of this rate over 200-400 K has yet to be measured. This rate must be consistently incorporated into calculations of all three terrestrial planet thermospheres.

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Independent one dimensional (1-D) model studies of the Venus dayside heat budget [2,3] were recently conducted which confirm the need for a fast (2-4 x 10^{-12} cm^3/sec) relaxation rate [2,3]. Also, the newly simulated Mars dayside heat budget [3] is consistent with CO_2 cooling derived from a fast (2-3 x 10^{-12}) relaxation rate. For Venus, this strong cooling serves as an effective thermostat that gives rise to a small variation of thermospheric temperatures over the solar cycle, just as observed. Conversely, CO_2 cooling does not appear to be dominant in the dayside heat budget of the Mars thermosphere, yielding larger observed temperature variations. For the Earth, this strong cooling implies that the lower thermosphere does not require significant eddy diffusion or heat conduction, consistent with independent estimates of a weak mesopause eddy coefficient. Our ability to predict the clearly visible thermospheric "CO_2 greenhouse" cooling response into the 21st Century is directly dependent upon the proper incorporation of this CO_2-O relaxation rate in current modeling schemes [4]. This comparative approach provides the broadest range of conditions under which a common CO_2-O relaxation rate should provide consistent results.

Future measurements are needed that address the laboratory CO_2-O rate over 200-400 K. Also, the discrepancy between laboratory and atmospheric derived values of this rate must be resolved. In particular, what role does hot oxygen play in exciting CO_2 vibrational states, thereby enhancing CO_2 15-μm cooling?

TABLE 1. Recent Estimates of CO_2-O Relaxation Rates

Value (10^{-12} CM^3/SEC)	Temp. (K)	Technique	Reference
6±3	300	CO_2 Radiance (SPIRE Rocket)	[8]
5-6	200-400	CO_2 Radiance (SPIRE Rocket)	[10]
1.5±0.5	300	Laboratory	[9]
1.2±0.2	306	Laboratory	[6]
1.5 - 6	300	CO_2 Absorption (ATMOS)	[7]
3-6	200-400	CO_2 Absorption (ATMOS)	[5]
2-4	300	Venus GM Model	[2,3]
2-3	300	Mars GM Model	[3]

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